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Discrepancies in a Virtual Learning Environment: Something “Worth Communicating About” for Young Children with ASC?

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ABSTRACT

This paper explores the phenomenon of young children with *autism spectrum conditions* (ASC; aged 5-8 years) detecting *discrepancies* (i.e. novel or rule-violating occurrences) in a *virtual environment* (VE), and their subsequent reactions. Analysis of existent video data of 8 children with ASC interacting with the ECHOES VE showed that they detected and reacted to a range of discrepancies. More importantly, these discrepancies motivated a range of positive, social initiations, such as sharing affect, commenting, and social referencing. These early results suggest that deliberately including discrepancies in VEs may motivate initiation for children in this group. However, little is known about the possible types of discrepancies that might exist in a VE, how this population understands them, and how they might practically be incorporated into future designs.

General Terms

Design, Experimentation, Human Factors

Keywords

Autism, children, social communication, initiation, virtual environments, discrepancy, novelty, HCI

1. INTRODUCTION

There are a range of technologies which aim to support children with *autism spectrum conditions* (ASC) in completing daily-life tasks and learning foundational skills. Persons on the autism spectrum experience particular difficulty with social and communicative behaviours, and also tend to show relatively narrow interests and a strong preference for sameness (see Section 2.1). The predictability, repeatability, and relative simplicity of technologies (compared to human-human interaction) are given as reasons why they are particularly suited to, and motivating for, this population [1].

Recent observations from the ECHOES technology-enhanced learning project ([2], see Section 4.1) suggest that even when technologies, particularly *virtual environments* (VEs) and *virtual characters* (VCs) are *unpredictable*, they may still support and

motivate young children with ASC. In an analysis of children with ASC working with ECHOES, it was noted that intermittent software errors¹ unpredictably altered the behaviour of both the VE and VC, violating child expectations about how the environment “should” behave. There were multiple examples of children reacting to these errors and to [intentionally] unexpected elements (such as new digital objects) by making spontaneous, social initiations, including shared positive affect, verbal comments, and social referencing. Overall, these *discrepant aspects* appeared to be perceived as fun or humorous. Such reactions are noteworthy in this population, both because of the relative paucity of initiation from children with ASC and the prevalence of rigid, restricted, behaviours and routines (see Section 2.1).

Discrepancy is not an inherent property; it exists in the child discovering a “mismatch” when s/he makes a comparison between the current aspect and his or her knowledge, expectations of, or predictions about the environment. This mismatch may result from a *novel* aspect, one which is as yet unknown and about which there has not yet been an opportunity to develop expectations. Alternatively the aspect may be a *surprise*—something is known about it, but it does not behave as expected. Discrepancy is further discussed in Sections 3.4 and 4.2.

Given the importance of structure for reducing anxiety for people with ASC (e.g. [3]), the obvious enjoyment of discrepancies in ECHOES seems puzzling. The literature would predict that apparently random rule-breaking could be a source of distress. However, these observations suggest the opposite: discrepancies were fun and “worth communicating about”.

The research described in this paper is empirically motivated by these initial observations, with the goals of determining:

1. Whether these reactions to discrepancy are isolated occurrences, or part of a wider pattern;
2. Whether such reactions were limited to specific children, or common across the participant group.

Given the known difficulties in social interaction which are associated with ASC, the research centres on investigating the extent to which discrepancies might motivate social communication for this population. The focus in the current research is on exploring the basic nature of the discrepancy-reaction phenomenon in the existent data (individual young

¹ Note that “errors” here does not mean system freezes or crashes, nor error messages. It means errors in the sense of the system executing the “wrong” action with respect to an activity’s goals, an object’s usual behaviour within the VE, etc.

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children with ASC using a VE), rather than consideration of other technologies or contexts of use, e.g. “face-to-face” social communication. Based on this analysis, the paper goes on to consider whether deliberate discrepancies might be used as a design strategy, forming the basis for facilitating social interaction within or around future VEs.

2. ASC AND COMMUNICATION

2.1 Core Characteristics of ASC

The ASCs are a set of pervasive developmental conditions, characterised by notable difficulties in communication and social interaction, plus the presence of repetitive behaviours and/or interests [4]. A significant minority of persons with ASC have extremely limited language or are nonverbal². Due to the heterogeneous nature of the autism spectrum, two individuals with the same diagnostic label or same score on a standard measure such as the Autism Diagnostic Interview-Revised (ADI-R; [5]) may have little in common otherwise in terms of both their strengths and their qualitative impairments.

Children with ASC³ tend to initiate all types of communication infrequently compared with TD or developmentally delayed (DD) peers [6]. Neurotypical humans frequently initiate communication for the purpose of affective *social sharing*, “seeking to share enjoyment, interests, or achievements with other people (e.g., by showing, bringing, or pointing out objects of interest to other people)” [7, p. 70]. TD children and adults find the reciprocal interest and affect of social sharing strongly motivating, but individuals on the autism spectrum are relatively unlikely to engage in this particular type of spontaneous socio-communicative behaviour [6], and its absence is a key diagnostic criterion for ASC [7].

There is widespread agreement that early childhood interventions to improve social communication provide a better chance of positive outcomes later in life (e.g. [8]), given that social communication can be considered a foundation upon which more advanced skills are built. For example, *joint attention*, or the ability to establish a shared focus of attention with another person (and one or more objects) is an important component of any reciprocal social interaction and indeed, of the majority of types of learning. Several studies have demonstrated strong positive correlations between joint attention skill in young children with ASC and their capacity for language use up to ten years later [e.g. 9]. The centrality of social communication difficulties means that these skills have been a target of educational and psychological interventions, both with and without technology (e.g. [10]).

2.2 Technologies to Support ASC

Interactivity and experiential learning are already strong arguments for using technology as an aide to teaching; the research literature argues that technologies may be a particularly good fit for people with autism (e.g. [1]). Many technologies can be made repeatable, predictable, and limited in their content and attentional demands. They are also controllable: potentially

distracting or threatening stimuli may be stripped out, while important information may be emphasised.

Technological supports for autism have addressed a range of goals. Some focus on teaching specific skills such as facial emotion recognition (e.g. the *Transporters* videos [11]) or joint attention (e.g. the ClickEAST iPad app [12]). Others are oriented towards supporting daily-life demands, either by providing safe and repeatable practice for a task (e.g. choosing a bus seat [13]) or by providing a scaffold or reference (e.g. scheduling apps such as vSked [14]). A third group of technologies are more open-ended, seeking to facilitate social interaction and play between multiple persons with ASC, or between a person with ASC and a neurotypical partner (e.g. [15]). The ECHOES technology-enhanced learning project [2], which provides the starting point for the current work, blends opportunities to practice foundational social skills such as joint attention with exploratory, playful elements intended to more generally facilitate interaction (see Section 4.1. for further description of ECHOES).

3. MOTIVATING SOCIAL COMMUNICATION

3.1 Motivation and the environment

Social communication, particularly joint attention, may not be intrinsically motivating to a child with ASC in the same manner (or to the same degree) that it is for a TD child (e.g. as discussed in [15]). It is possible that some children with ASC are motivated by the tangible rewards of communications that allow them to gain access to objects or assistance from others (i.e. *imperative* communication), but not by the social rewards of sharing-type behaviours [15, 16]. This suggests that if the social component of information sharing is not (sufficiently) intrinsically motivating for a child to initiate those behaviours spontaneously, the motivation to share or comment needs to be *extrinsic*, out in the world.

Unfortunately, the highly structured, timetabled, *predictable* environments that may support children with ASC and reduce their anxiety may also limit the extrinsic motivations for them to communicate. Needs may be met by carers ‘reading’ the child, rather than the child initiating. However, if an environment can effectively remove the need for communication, it could also be altered in the opposite direction, to become “worth communicating about” in a way that it was not before.

Many highly structured, adult-directed programmes such as discrete trial training (e.g. [17]) have used attractive but arbitrary extrinsic motivators (e.g. snacks, tokens) to aid in teaching small “pieces” of behaviours or language, often through massed trials consisting of repeated adult prompts and child responses. These approaches *can* help to teach communicative behaviours, but these are unlikely to be used appropriately (over time) outside the experimental/clinical situation because the motivators are no longer present. This problem suggests that extrinsic motivators with some inherent relationship to the type of communication being taught will have an advantage at teaching and maintaining those behaviours “in the wild”. One extrinsic motivation strategy has been to increase or vary the communicative demands that are already present in the child’s environment (e.g. [18, 20, 21]; see Section 3.2). Changes might include removing, hiding, or altering objects so that the child is obliged to initiate communication in order to obtain them or to receive assistance.

² Lord and colleagues estimate the figure at about 50% [5].

³ By “children with ASC” we are not referring to those diagnosed with high-functioning autism or Asperger syndrome. Such children may show a very different communication profile to our target group, and indeed may struggle to *limit* their initiations to appropriate people, places, and topics.

3.2 Discrepancy as an Extrinsic Motivator

Modification of a child's environment to include deliberate *discrepancies* appears to be a promising source of extrinsic motivation which, although not an entirely new strategy, has yet to be systematically explored. It is largely addressed anecdotally in general books for parents and carers of children with ASC, with the goal of enhancing communication [18, 20]. The overall strategy is to create the *necessity* to initiate communication, altering the environment so as to embed communicative demands in contexts that are *already motivating* to the child, such as snack or play time. For example, the child might discover that the usual peanut butter jar is filled with frosting, or be given a spoon that is too large to fit into the yoghurt container [22]. Another suggestion is to violate object function, such as giving the child an incorrect or broken item with which to perform a familiar task [21].

An experimental study [23] with DD children compared their responses to an activity with unexpected, script-violating events (similar to the type of unexpected events described above) and to a control activity without them. In both activities, the child played one-on-one with a researcher using water and toys. Results suggested that introducing unexpected events succeeded in increasing all participants' number of verbal responses to the researcher, compared to the control condition. The communications were spontaneous (i.e. not prompted) and were relevant to the environment. Unfortunately, [23] focused on supporting verbal *responses*, and provides no data on non-verbal responses, or on children's initiations about unexpected events.

The environmental modification strategies reported for face-to-face contexts appear easy-to-apply and anecdotally effective for individual children. However, there has been little commentary on practical questions such how to choose appropriate strategies (and when/how often to use them). Also unreported are examples of *failed* discrepancies that proved overly frustrating, too subtle to sufficiently motivate communication, or simply unsuitable for particular children. In short, there is not yet a clear template for other researchers or designers to follow, should they wish to incorporate these strategies in a new intervention. It is still an open question whether or to what degree such strategies meaningfully translate into virtual contexts. The current work cannot provide definitive answers to the "practical questions", but aims to determine—based on the discrepancies present in the ECHOES data—whether virtual environments might be systematically modified to extrinsically motivate social initiation.

4. AN ANALYSIS OF DISCREPANCY AS A COMMUNICATIVE MOTIVATOR

4.1 The ECHOES project

4.1.1 Overall project goals

The ECHOES project developed a technology-enhanced learning environment targeted primarily at young children with ASC, but with the potential for use by TD children [2, 24, 25]. ECHOES includes a programme of game-like learning activities set in a "Magic Garden" VE, and designed to scaffold the child in exploring foundational social and communicative skills, including imitation, point- and gaze-following, and turn-taking. By bringing together cutting-edge hardware and AI planning with educational and psychological theory, the project team's goal was to deliver an engaging learning experience suitable for children with a range of developmental trajectories. Participatory design was central to the process of developing ECHOES and included children with and without autism, teachers, and other stakeholders [26, 27].

4.1.2 Hardware, Magic Garden VE, and VC

The ECHOES VE was designed for a free-standing 42" multi-touch screen. A young child user standing or sitting in front of the screen can be immersed in the visuals and sounds of the Magic Garden, and be quite physically involved in the interactions (variously dragging, tapping, shaking, and tickling digital objects). Speech and sound output are present, but are pre-recorded with no text-to-speech capability. There is also no capacity for speech recognition or other sound input.

The Magic Garden is home to Andy, an autonomous, childlike virtual character, who is meant to be the child's guide and playmate throughout the learning activities. The underlying AI software modules plan Andy's behaviour both deliberately and in reaction to the child's actions (or non-actions) in the system (for details, see [25]). A researcher at a small monitor alongside the main ECHOES screen used a GUI to manage inter-activity transitions and give limited system commands (such as for Andy to repeat an instruction). ECHOES is not a Wizard-of-Oz system; the researcher's degree of control was minimal, and mostly meant to keep the overall session flowing smoothly.

ECHOES activities encouraged experimentation and play by deliberately introducing novel elements and behavioural fantasy (the "magic" of the Magic Garden). Examples include "pulling" on flower heads to transform them into bubbles or bouncy balls, or a box of balls becoming buzzing bees or a fireworks display when a sorting task is complete.

4.1.3 In-school Summative Evaluation

Summative evaluation of ECHOES took place in Spring and Summer 2011 (results in preparation), and included 28 children with ASC from four UK school sites (see Section 4.3.1 for details of participants and school sites).

The broad goal of the ECHOES summative evaluation study was to assess a variety of social and communication skills before, during, and after six to eight weeks of using the ECHOES environment. Children completed several 10-20 minute sessions of game-like learning activities per week, gradually introducing more complex material over the course of the study. Video data was the primary record of the child's communication and social behaviour, as automatic logging captured touch-screen actions only. Each session of the child playing with ECHOES was recorded by a digital camcorder on a tripod, 5-7 feet away from the screen. A subset of this video data forms the basis for the preliminary analysis reported in Sections 4.3.3 and 4.4.

As an ECHOES foundation study discovered, children frequently interacted with the researcher(s) as well as the system [24]. As a result, the camera was positioned to capture as much as possible of the broader study environment (screen, child, and researcher). Children sat on a chair within easy reaching distance of the touch screen. At evaluation site 1, one experimenter sat near the main screen, controlling the environment from a second monitor (the screen of which was not visible to the child) and providing support to the child (see Figure 1). A second experimenter operated the camcorder. At evaluation site 2, both experimenters sat further away from the child and out of the child's field of vision (due to a larger room), with one controlling the environment and the other providing support as needed.

4.2 Taxonomy of Discrepancies and Reactions

4.2.1 Discrepant Environmental Aspects

As introduced in Section 1, *discrepancy* is a high-level category encompassing any instance in which a current aspect of the

environment x is mismatched with the child's current knowledge or expectations about the environment and its contents.

It is worth highlighting that discrepancy has a child-centred rather than system-centred definition in this work. As noted previously, discrepancy is not inherent to the VE, even through several of the examples later involve the system doing things that are objectively “wrong”. It is defined in relation to the *child's* interaction with the VE and the *child's* understanding of how that environment does or “should” work. If the child makes no comparison, *then there can be no discrepancy*. Thus, the child may appear unsurprised by events that are, objectively, in violation of the VE's established patterns, of physical laws, etc. because from his/her viewpoint, these aspects are perfectly coherent. The appropriate unit of analysis is thus the *discrepancy-child reaction pair*, not discrepancies alone.

Of course, the child's understanding of the environment is generally private, with explicit statements of expectation or prediction relatively rare. The main source of information available when attempting to infer the presence of discrepancy-reaction pairs is the annotator's knowledge of what the child has been exposed to in the environment (and how many times). What evidence might s/he have about what is in the environment, and how it all works? In some cases, there may be additional information available from developmental psychology, such as guidance on what children of a certain [developmental] age are likely to understand about concepts like object permanence, cause-and-effect relationships, etc.

Discrepancies can be divided into three main subcategories based on the source of the mismatch between aspect x and the child's internal model of the environment: novelty, surprising events, and non-events. These subcategories and their characteristics are summarised in Figure 2, and discussed later in this section.

4.2.1.1 Surprising Events

These discrepancies could be most simply summarised as “expectation-violating events”. An instance x of a known type X (or sufficiently similar to known instances of X that there could be reasonable expectations about its behaviour) occurs or is present in the environment. However, it does not appear or behave as the user expected or predicted. The current x is discrepant from the expected x , but does not constitute a new kind X . Two event-reaction pair examples drawn from the data set are given below, both with social child reactions.

1. Unexpectedly, Andy walks off-screen in the middle of an activity and does not return. The child makes a social reference to the researcher, and then looks back to the screen. The researcher initiates an interaction by asking the child where he thinks Andy has gone.
2. Andy demonstrates a sorting activity, putting balls into boxes of the same colour. After several child turns, Andy tries to put a yellow ball in the red box (see Figure 3), only for it to roll off the top. The child points to the correct box and excitedly shouts “Right here!”



Figure 1 Experimental set-up from Site 1. The researcher is seated at the control monitor (not visible).

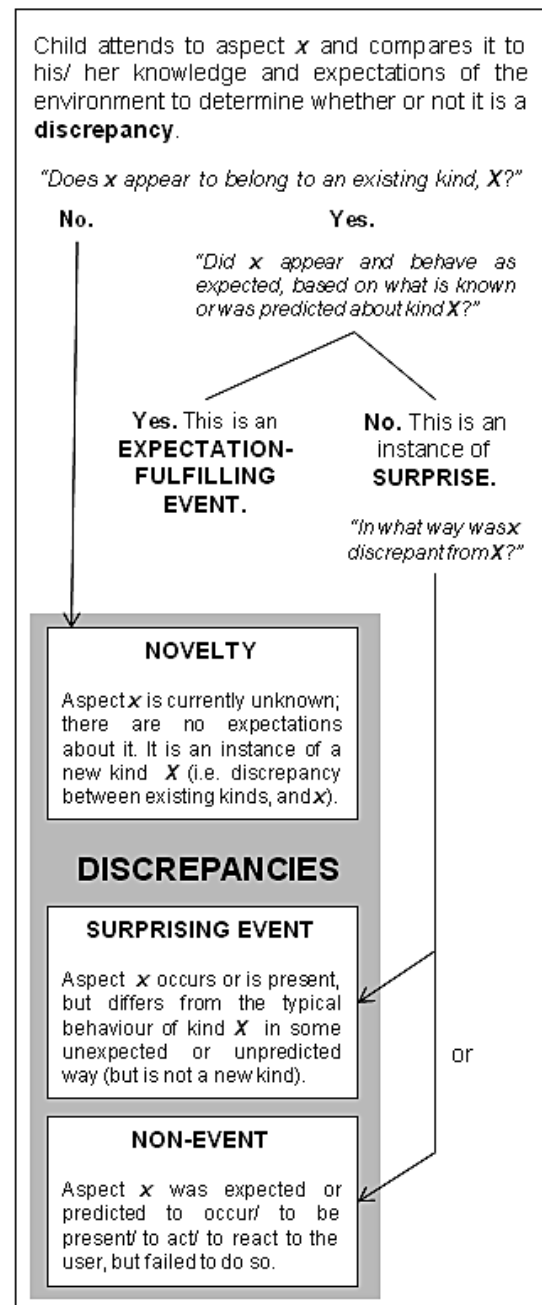


Figure 2. Decision tree for determining whether or not an environmental aspect is discrepant or expectation fulfilling.

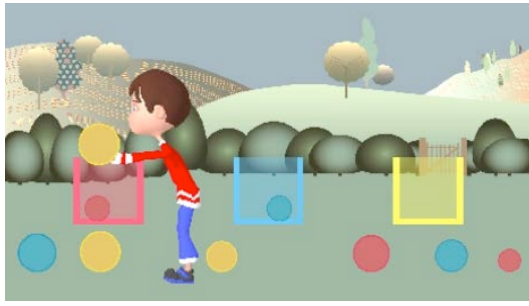


Figure 3. Andy incorrectly sorts a ball, motivating the child to give him an instruction about where it should go.

4.2.1.2 [Surprising] Non-Events

These discrepancies are defined similarly to surprising events, except that they concern violations of expectation through aspects of the environment unexpectedly/unpredictably being absent or failing to occur. In other cases, objects or the VC may be present as expected, but do not perform any of their expected actions or may not react to user actions that customarily produce a response. Non-events do not mean a touch-screen failure or the entire system freezing; they are more selective issues, as the two data set examples below may illustrate.

1. In a flower-picking activity, Andy asks for the child's help and then gazes and points to one of the three available flowers. The child touches all flowers and none of them flies into the basket (indicating a correct choice). The child stops touching the screen and leans in to look very closely at Andy's face (i.e. social referencing; seeking information).
2. The Magic Garden fades in to start a new activity. There is an unusually long pause without Andy entering (i.e. compared to previous activities), but the system does not appear frozen. The child asks, "Where's Andy?".

As with surprising events, many non-event discrepancies originate from the user's incorrect beliefs and expectations about the environment or the effect of his or her actions. For example, some children repeatedly requested help with "broken" objects that

were not broken, but rather could not detect the child's inappropriate touch action (such as poking or scratching). From the child's view, however, there was a discrepancy between the expected result of the action and the object's failure to respond.

4.2.1.3 Novelty

Novel discrepancies are those in which the child encounters an aspect of the environment about which s/he has not yet had an opportunity to develop expectations— and that were additionally unexpected or unpredicted based on the child's current knowledge. In other terms, the aspect x is judged to be different enough (i.e. has a "large enough" discrepancy) from other known aspects that it is the first instance of a new type, X .

It is unclear how many exposures are required for the child to develop an expectation. To improve annotation consistency, an aspect was considered novel the first three times a child was exposed to it in the video sample, and then ceases to be annotated as discrepant (even if the child continues to react to it). If the aspect violated physical laws, object relations, or other expectations that the child would be expected to have from outwith the environment, it was still treated as a potential instance of novelty and was subject to the "three exposure rule".

Two example novelty-reaction pairs are given below, with one social and one non-social child reaction.

1. A child hears a particular sound effect for the first time, and exclaims to the researcher about the "music".
2. A child sees Andy demonstrate throwing a ball through the cloud for the first time, changing its colour. The child laughs and claps, facing the screen (non-social reaction).

4.2.1.4 Familiarity

In the current taxonomy, the opposite of discrepancy is *familiarity*. That which is *familiar* is of a known type of object or event, rather than a new one, and behaves as would be expected or as could be reasonably predicted. For example, Andy putting the yellow ball into the yellow box would be familiar. The majority of the events and objects in ECHOES are of this type.

Table 1. Participant information (pseudonymous)

Site	Child (Gender)	Age	SCQ	BPVS scores		Description
				Raw	VMA	
1	Anthony (M)	7 y. 5 mo.	23	51	5 y. 0 mo.	Child has conversational-level language with very little echolalia.
	Odell (M)	7 y. 7 mo.	25	30	3 y. 2 mo.	Child has phrase-level language with very little echolalia. Generally very quiet manner; appears to prefer nonverbal communication.
	Lucy (F)	8 y. 1 mo.	28	11	<i>Est. 2yr.*</i>	Child uses words and occasional phrases with some echolalia.
	Russell (M)	7 y. 5 mo.	23	33	3 y. 3 mo.	Child has phrase-level language; some echolalia.
2	Ethan (M)	5 y. 5 mo	23	44	4 y. 3 mo.	Child has at least phrase-level language with some echolalia. Very inconsistent amount & complexity of language across data set.
	Hadi (M)	5 y. 0 mo.	4/23 [†]	30	3 y. 2 mo.	Child uses words and occasional phrases with some echolalia.
	Kalil (M)	5 y. 11 mo.	14	41	5 y. 10 mo.	Child has phrase-level to conversational-level language with very little echolalia.
	Ollie (M)	4 y. 11 mo.	16/26 [†]	30	3 y. 2 mo.	Child has at least phrase-level language with some echolalia.

* Child unable to complete full BPVS task. VMA estimated based on related language measures administered by the school's SLT.

[†] Multiple SCQ forms returned for child. Scores from parent (L) and teacher (R).

4.2.2 Child reactions

For the purposes of the current analysis, a child's *reaction* is his/her visible and/or audible behaviour contingent on some aspect of the environment. Reactions need not occur immediately after an event; they may be delayed, or there may be more than one reaction over a period of time. The form of the reaction will vary based on the child, and may include any behaviours (or combination thereof). If there is an identifiable affective state, it may have any valence. A reaction does not require communicative intent or direction to a social partner (i.e. to be an *initiation*). Those reactions that are contingent on a discrepant aspect but are not socially directed are included in the taxonomy as *non-social reactions*.

4.2.3 Initiation

A *reaction* that is spontaneously and purposively directed to a social partner is an *initiation*. When a child *initiates* s/he begins a "new" interaction that is not contingent on the social partner's previous action, i.e. has no defined antecedent in the immediate past communications between those particular partners. Initiation is a top-level category that includes behaviours of many forms and functions. A child reaction to discrepancy may be labelled as an initiation as long as it is—as far as can be determined—not contingent on the social partner's previous action and fulfils these three additional criteria:

- It is *spontaneous* (i.e. not the result of an explicit prompt to perform that behaviour, or a similar one)
- It is *purposive* (goal-directed), rather than accidental
- It is *directed* to a social partner (e.g. on the basis of the content of the behaviour or utterance, child's physical orientation towards the partner, child's intonation or volume, or other cues)⁴

This is a deliberately broad view of initiation that seeks to credit participants' efforts, however unconventional those may be, and whether or not they are understood by the social partner. A child's behaviour can count as an initiation even if the social partner does not appear to be aware of the child's effort, does not react to it, or apparently misinterprets its meaning.

4.2.3.1 Response

In order for the child's behaviour to be a *response*, it must be contingent on a previous social partner action *that was directed to the child*. In short, a child can only make a response if the partner has made an initiation. If the child's socially-directed behaviour is contingent on a recent social partner action that was *not* directed to the child, the child is actually initiating because he is not continuing a current interaction.⁵ In the current analysis, responses are only explicitly annotated when they are part of a *sequence of interactions* (see Section 4.3.4 for more on sequences) in which an initial child initiation and partner response are then followed by further "moves".

⁴ *Direction* may be determined on the basis of content, physical direction to/ orientation towards the partner, or the child's usual patterns of behaviour.

⁵ *Reaction* and *response* are not synonymous. In the current data and taxonomy, a child cannot *respond* to a discrepancy because none of the current discrepancy examples are directed *to the child*.

4.3 Method

4.3.1 Participants

The children included in this analysis were participants from two sites of the ECHOES summative evaluation study (in preparation), whose data have been re-analysed here. Site 1 is a small UK primary school for intellectual disabilities, with an autism-specific class. Site 2 is a medium-to-large UK primary school which includes an autism resource base. Participants from this site spend some time each day in a mainstream class, in addition to their specialist provision. All participants were initially recruited through informational materials distributed by their school administration on behalf of the ECHOES project.

The primary recruitment criterion for the ECHOES study was that each child had a previous diagnosis of an ASC by a paediatrician, child psychiatrist, or other professional. The ECHOES project did not re-confirm participating children's diagnoses, but administered two standard measures in order to gain a better picture of each child's linguistic and social ability: the British Picture Vocabulary Scale (BPVS; [28]), a measure of receptive language ability,⁶ and the Social Communication Questionnaire (SCQ; [29]) a caregiver questionnaire about a child's ASC-relevant characteristics and behaviours.⁷

Not all evaluation participants fell within the target developmental age range for ECHOES, or used verbal language. This was generally due to teachers requesting that all children in the same class be able to take part. For the analysis reported in this paper, participants were selected on the basis of being closest to the ECHOES target group, with phrase-language use or better and sufficient data for analysis (at least 30 minutes), yielding 8 participants out of the 13 total at sites 1 and 2. Table 1 reports participants' demographic information and test scores, including their verbal-mental ages (VMA) calculated based on BPVS scores. The disparities between VMA and calendar ages suggest that all but one child has some degree of intellectual disability in addition to ASC.⁸

4.3.2 Materials

4.3.2.1 Video Data

This study uses 347 minutes of video data collected during the ECHOES summative evaluation, with three fifteen-minute samples per child from chronologically early, middle, and late sessions with the VE (to capture the new material introduced throughout the study). Samples excluded non-analysable video (e.g. system crashes, child rest breaks) and learning activities in which the VC was not present, as this would have resulted in unequal opportunities for the child to initiate to the human researcher versus the VC.

⁶ BPVS scores were obtained from the school's speech and language therapist (SLT) at Site 1, and collected by trained ECHOES researchers at Site 2.

⁷ The SCQ is based on the ADI-R [5] and often used as a screening tool for ASC. A higher score generally indicates more severe difficulties, with 15+ (out of 40) taken to indicate the presence of pervasive developmental disorder or an ASC. SCQ forms were completed by each child's parent or guardian.

⁸ Intellectual disability frequently is comorbid with ASC, affecting an estimated 40-80% of individuals [4].

4.3.2.2 Software

Each child's video samples were annotated by the first author using the ELAN Linguistics Annotator [30]. All templates were created based on the taxonomy described in Section 4.2. Finished annotation data was exported from ELAN as tab-delimited text and further analysed in a standard spreadsheet program.

4.3.3 Analysis

4.3.3.1 Preliminary Video Annotation

The purpose of the preliminary annotation stage was to locate and describe discrepancy-reaction pairs. Taking a child-centred view of discrepancy makes sense, but makes for tricky annotation. Events and non-events that could objectively be considered violations of the system's usual patterns (e.g. the VC making mistakes) often signalled video sections including discrepancy-reaction pairs, as did the introduction of a new activities or objects. Finding discrepancies *not* clearly related to system errors involved carefully observing the child's interaction with the environment, looking for cause-effect relationships between the system content and the child's behaviour. Where the child made an initiation, attempts were made to determine both the aspect(s) that motivated the reaction, and what the child might know or expect about those aspects. This process is ultimately subjective, but it is more likely to falsely identify a discrepancy as the cause of a child reaction than it is to find a reaction where none exists.

The ELAN template for discrepancy-reaction pairs captured the following information:

- Description and categorisation of the discrepancy (surprising event, non-event, or instance of novelty).
- Description of the child's reaction and preliminary categorisation of the child's (re)action (initiation to partner, non-social reaction, or response to partner during an ongoing *sequence* originally initiated by the child). See Section 4.3.4.

The ELAN template also noted whether an initiation was *primary* (the first reaction to that instance of discrepancy) or *secondary* (any subsequent reactions to that same instance of discrepancy). The latter becomes important when determining whether the child and a social partner are engaged in a *sequence* of interactions about the same discrepancy. Note that there is no non-social counterpart to a secondary initiation, as it is unlikely that subsequent non-social reactions, removed in time from the initial discrepancy, could be confidently identified as being motivated by that *same* discrepant aspect, rather than something else in the environment.

4.3.4 Spreadsheet-based Analysis

Completed annotations were exported to a standard spreadsheet program as tab-delimited text, with each line of the spreadsheet containing all relevant information about a single discrepancy-reaction pair. Secondary reactions appeared on separate lines. The spreadsheet-based analysis consisted of several tasks:

1. Revisiting the open-ended descriptions of the child's social reactions to confirm that they constituted initiation. Those behaviours that did not qualify were tagged as non-social reactions, or discarded if the behaviour was decided, upon further review, to be unrelated to discrepancy.
2. Any descriptions of non-social child reactions were given a code based on their estimated valence (positive, neutral/unclear, or negative).

3. Any *sequences* were identified and their constituent lines of data copied to a separate "sequences" sheet for further analysis, namely checks for reciprocity of interaction.

Any initiation followed by one or more secondary initiations constitutes a *sequence*. Some sequences (or parts thereof) may furthermore constitute a *reciprocal interaction sequence*, a multiple-turn interaction in which child and partner exchange two or more consecutive initiation-response pairs, with at least one initiation from the child. This concept is adopted from the SCERTS framework [22].

Reciprocal interaction sequences are of particular interest because they could be considered more advanced, in a developmental sense, than single initiations or responses. An ongoing interaction requires social partners to coordinate their efforts, if they are to make contingent, relevant interactional moves. Contingency (especially in verbal language) is thought to build on simpler joint attention skills because of this coordination requirement: it requires both parties to coordinate their communicative efforts. Thus, while it is positive if discrepancies are able to motivate *any* social initiations at all, it is even more positive if they motivate children to *maintain* an interaction over several turns, giving the social partner additional opportunities to respond to the child and/or to generally scaffold the interaction.

4.4 Results and Discussion

4.4.1 Child Reactions to Discrepancy

Table 2 summarises the number of social and non-social child reactions for each of the 3 categories of discrepancy. Though small, the participant group includes children from 2 different school settings and represents a range of both language proficiency and degree of intellectual disability: it is noteworthy that all 8 children in the analysis *consistently* reacted to discrepancies. Each child had between 21 and 38 discrepancy-response pairs (mean= 29.87, SD=5.22) with a total of 239 in this data set. Considering these counts in relation to the total length of the video samples (45 minutes per child), children appeared to detect discrepancies not only regularly but *frequently*. This is not to claim that another system or subset of participants would show a similar pattern.

Many surprises continued to elicit reactions throughout the evaluation study. ECHOES content was repeated across sessions (often in conjunction with introducing new material) and thus most discrepancies recurred—for example the VC making "mistakes" due to AI planner errors. This is very encouraging when considering deliberate inclusion of discrepancy in future designs. While novelty inevitably has a limited shelf-life, surprising events or non-events would be of little use if they only motivated communication the first time they were seen.

A "meta-conclusion" from this data is that the young participants with ASC formed specific expectations about the VE and the VC. As previously discussed, reacting to a discrepancy requires that an individual make a comparison between the current aspect *x* and his or her internal model of the environment and its rules. The individual must *have* knowledge and expectations in order to identify that something has not previously been encountered (is novel) or contradicts expectations in some way (is surprising). Some children were quite specific in identifying exactly how an aspect differed from their expectations, such as by identifying what the "correct" action would be after Andy made a mistake (see example 2 in section 4.2.1.1).

4.4.2 Initiations

Considering again the particular social and communicative challenges of people with autism (Section 2), perhaps the most notable result was that a mean of 61.91% of child reactions to discrepancy were initiations to either the human researcher or the VC, Andy. In other words, more than 3 out of 5 reactions to discrepancy were directed to a social partner (see Table 3 for the percentages of social versus non-social reactions for each discrepancy category).

These initiations were overwhelmingly positive or neutral in affect, with only a few instances of obvious frustration, and zero instances of the child “melting down” because the environment was breaking its own rules—an outcome that existing literature suggests is very possible in such a situation (see Section 2.1). At no point did any of the eight participants become severely emotionally dysregulated following a system discrepancy.

4.4.3 Interaction Sequences

A number of initiations to discrepant aspects were not isolated, but constituted the first of several initiations in a sequence. The number of reciprocal sequences for each child is listed in Table 4. All children engaged in at least one reciprocal interaction sequence (mean = 2.75 sequences), and at least one non-reciprocal sequence (mean = 4.37 sequences). While total numbers are small, they are *not* confined to the most able or verbal children (i.e. as estimated by their SCQ and BPVS scores). This is promising with respect to pursuing discrepancy as a possible strategy for the design of future VLE's that may be of benefit to a wide range of learners.

The following reciprocal sequence about a novel event is a fairly typical example of the length and complexity of the sequences in this data set. Here, Russell has just seen an animated “buzzing bee” reward for the first time, upon completing the sorting task.

Russell: *Turns to researcher. “Look, bees!”*
 Researcher: *“Yeah, bees.” Russell re-orientes to screen.*
 Russell: *He pulls his hand from the screen and gasps, pretending to be stung. He turns to look at the researcher, still holding his “stung” hand.*
 Researcher: *“Uh oh!”*
 Russell: *“Bees!” Gaze shifts from researcher to screen (where bees are now gone) back to researcher and repeats excitedly “Bees!”*
 Researcher: *Agrees “There were bees”.*

While unremarkable for a TD child, this sequence is quite a strong communicative example for a young child with autism, as it shows clear direction to the partner and spontaneously introduces an element of imaginative play (miming being stung by the bee) in which the child projects himself into the narrative space of the garden, where the virtual bees *could* physically affect him. Fortunately, he does not seem to find this frightening.

Many other sequences were not reciprocal because the social partner did not respond to the child's multiple initiations. Initiations directed to Andy were especially unlikely to succeed due to his limited information about what the child was doing. There was no way to detect child speech, or any other means for the child to attract Andy's attention other than by touching a task-relevant object. These “failed” reciprocal sequences could be considered prime opportunities to adjust the VE, the VC, or the broader child-adult-system environment, so as to facilitate future interactions. For example, it could be beneficial to expand the

GUI controls to include a “rapid response” prompt for Andy, even if the response was minimal. This is an approach in line with SCERTS [22] and other transactional intervention approaches that aim to follow the child's focus of engagement in order to extend or maintain an interaction.

Table 1. Social and non-social child reactions to discrepancy, by discrepancy type

Child	Novelty		Surprising events		Non-events		Child totals
	<i>Social</i>	<i>Non-social</i>	<i>Social</i>	<i>Non-social</i>	<i>Social</i>	<i>Non-social</i>	
Anthony	14	-	11	-	2	-	27
Ethan	1	4	-	-	10	6	21
Hadi	10	11	-	10	3	4	38
Kalil	8	6	4	3	9	2	32
Lucy	13	10	3	-	3	5	34
Ollie	4	4	-	4	13	5	30
Odell	7	4	4	6	5	-	26
Russell	17	5	5	-	4	-	31
Category totals	74	44	27	23	49	22	239

Table 3. Percentage of social versus non-social reactions across all participants, by discrepancy type

Discrepancies	Child reactions		Category Totals
	<i>Social (Initiation)</i>	<i>Non-social</i>	
Novelty	62.71	37.29	100.00
Surprising events	54.00	46.00	100.00
Non-events	69.01	30.99	100.00
Mean	61.91	38.09	100.00

Table 4. Number of sequences per child

Child	Non-reciprocal sequences				Reciprocal sequences			
	<i>Novelty</i>	<i>Surprising events</i>	<i>Non-events</i>	<i>Total</i>	<i>Novelty</i>	<i>Surprising events</i>	<i>Non-events</i>	<i>Total</i>
Anthony	3	3	1	7	3	-	-	3
Ethan	-	-	4	4	-	-	4	4
Hadi	3	-	-	3	1	-	-	1
Kalil	3	1	4	8	1	-	4	5
Lucy	2	1	-	3	1	-	-	1
Ollie	1	-	3	4	1	-	1	2
Odell	-	-	1	1	-	2	-	2
Russell	1	3	1	5	4	-	-	4
Total	13	8	14	35	9	2	9	20

4.4.4 Summary

The preliminary analysis strongly suggests that the participants formed specific expectations about the ECHOES VE and the VC, Andy, and reacted both to novel events about which they did not yet have expectations, and to surprises that violated their expectations. These discrepancy-reaction pairs appeared repeatedly throughout the data set and across all participants. A majority of these reactions were socially directed, with some initiations expanding into reciprocal interaction sequences.

5. GENERAL DISCUSSION

The environmental discrepancies that children detected during the ECHOES summative evaluation appear to have motivated a range of reactions, many of these directed to social partners and some of them beginning extended and reciprocal interactions. These reactions were remarkably consistent in number across the participant group, considering the wide range of general ability and language skills represented therein. These results are in themselves discrepant from those that might have been predicted based on the communicative difficulties and “need for sameness” well-documented across the autism spectrum. It is particularly promising for this line of research that most of the discrepant aspects appeared multiple times for the same child and were repeatedly followed by initiations. Discrepancy would not be a very useful design tool if each aspect could only be used once, and if hundreds of novel objects or surprises were needed in order to derive any communication benefits.

It is an open question why children reacted to those particular ECHOES aspects, and why they shared them with others. There are multiple reasons why surprises may hold inherent interest for a child with autism, ranging from the simple pleasure of novelty, to humour, to an interest in patterns and pattern violation. Currently it is not known what types of discrepancies might be most “worth sharing” or how many times a discrepancy can appear in the environment before it becomes unremarkable. There is only limited information about how many exposures are required to establish expectations about aspects of the VE or VC. An important question is why these particular discrepancies were overwhelmingly experienced as positive and even funny, rather than upsetting or as evidence of the VE being “broken”.

These results suggest that discrepancies may be a promising design element for VEs or other technological interventions targeted at young users with ASC. Determining their relevance for face-to-face interventions or for other age groups is outside the scope of the current work. The taxonomy presented in this paper provides a starting point from which to abstract away from individual participants and ECHOES examples in order to more generally understand the discrepancy phenomenon, and how it might be deliberately re-created in other technologies.

In summary, the phenomenon of discrepancies motivating spontaneous child initiations does not seem to have been recorded elsewhere for this population, and little appears to be known about it. Nevertheless, it may represent a promising approach to motivating young children with autism to initiate communication, at least within the specific context of a virtual environment. Deploying discrepancy as a viable design element in a full system is currently some way off. The questions posed above should be explored through targeted empirical work, with the goal of better understanding what discrepancy *means* to children with ASC, and what other types of discrepancy may be possible. This work may include a mixture of further analysis on the current video data, examining existent datasets of children using other interactive

technologies, and designing new, small-scale virtual activities in order to explicitly test hypotheses about discrepancy-reaction pairs. Exploring alternate taxonomies for the current data or newly-collected data, such as characterising discrepancies by their sensory rather than cognitive features, might also yield further insights in this area.

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